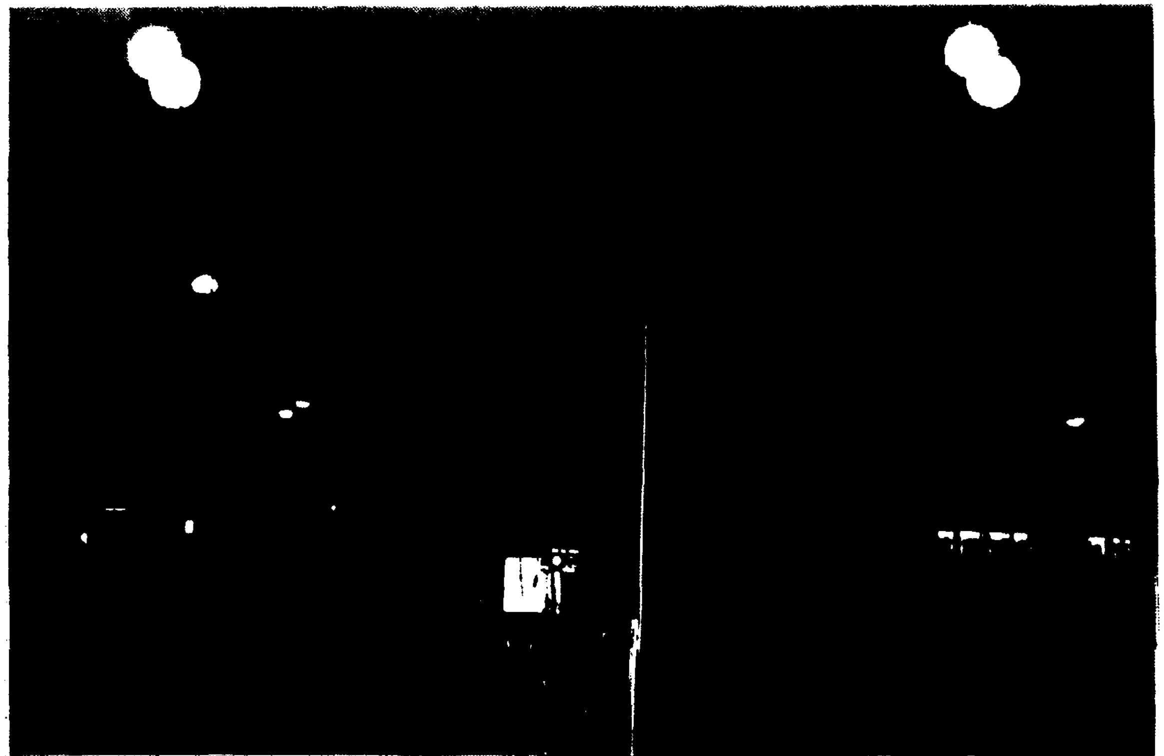
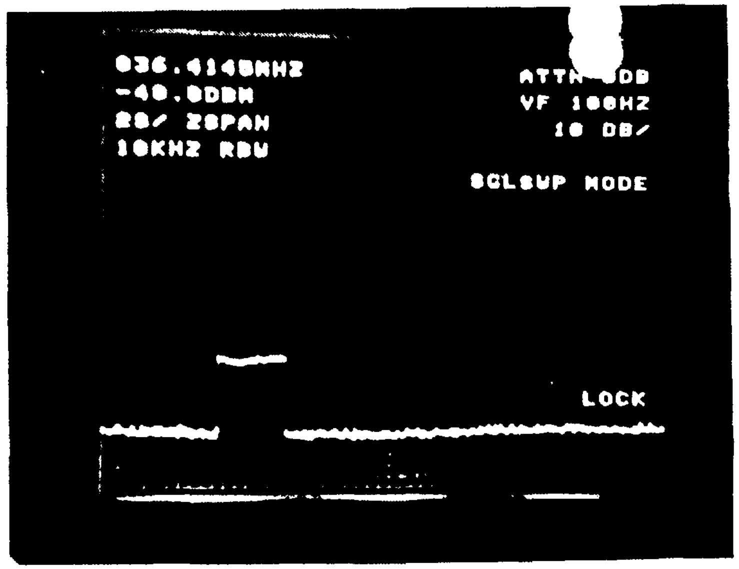
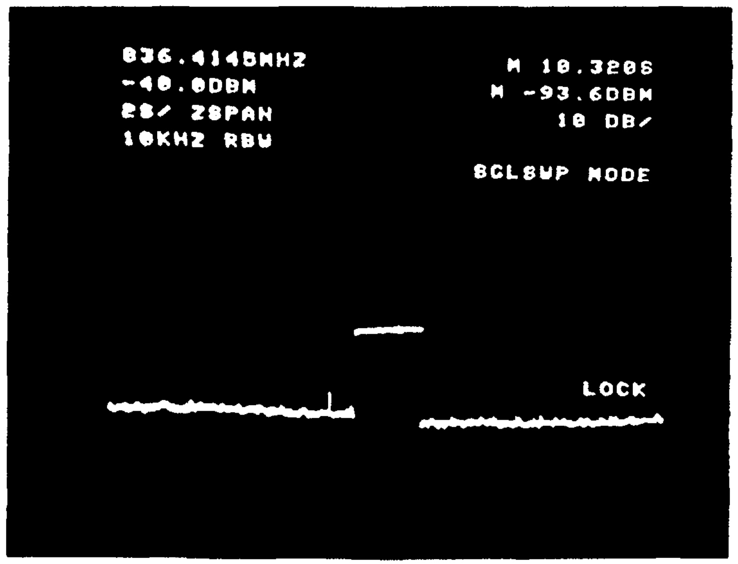
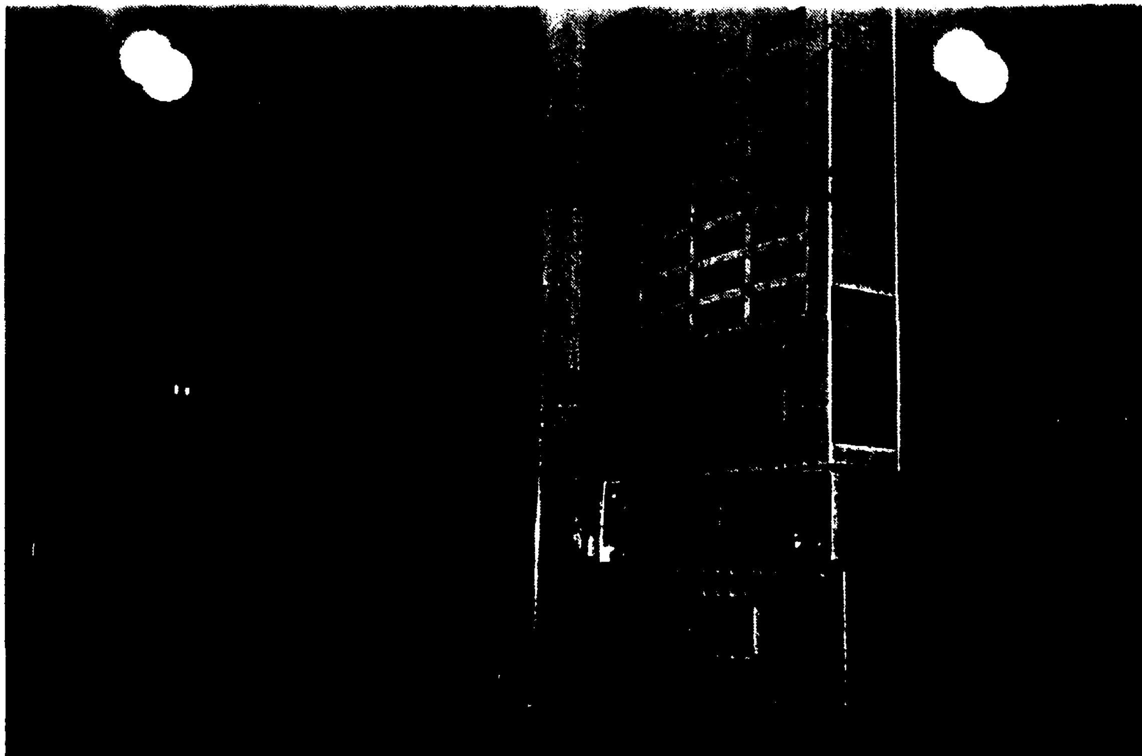


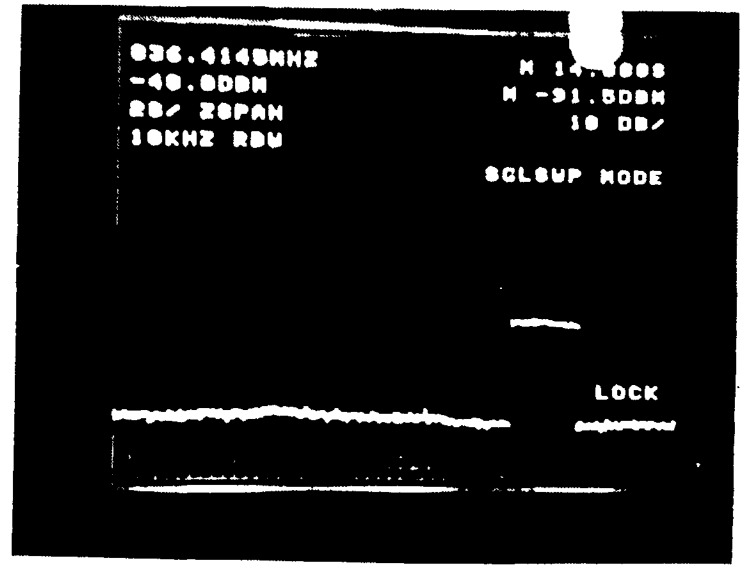


SITE 11: Dove Street & Washington, Behind Steel Pole

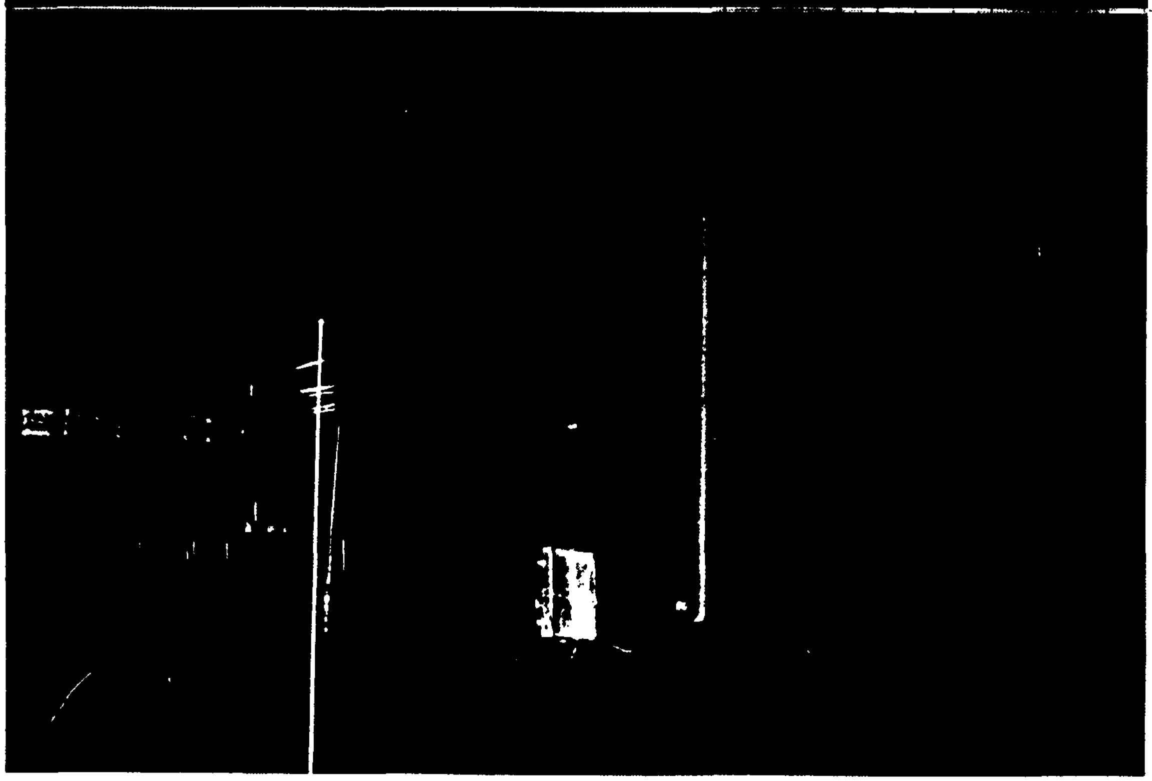


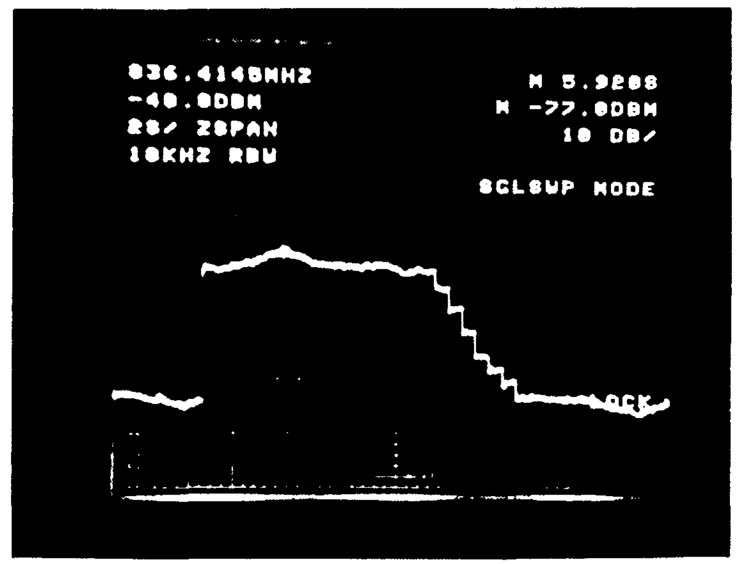
SITE 11: Dove Street & Washington, In Open



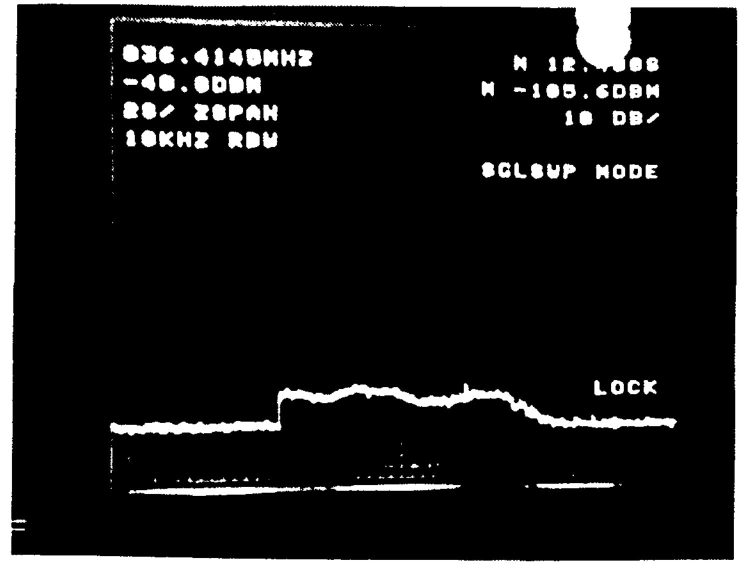


SITE 12: In Shadow of Hospital
(Inside Trailer)

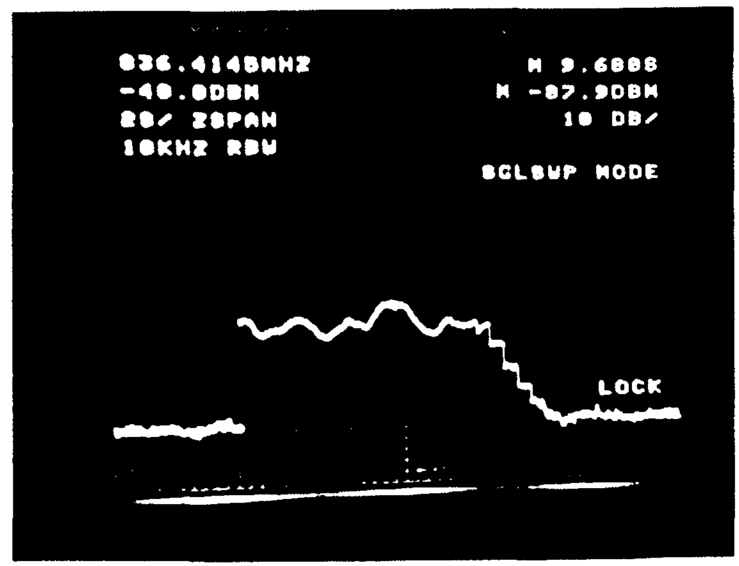




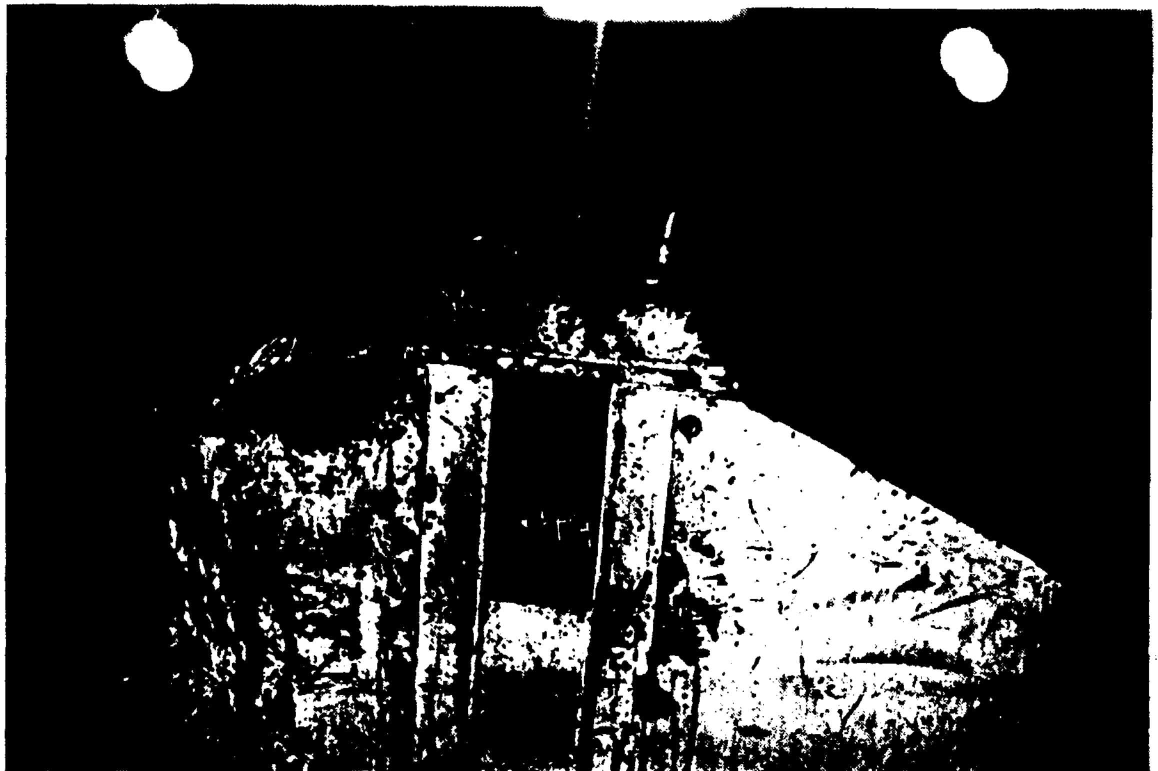
SITE 12: In Shadow of Hospital

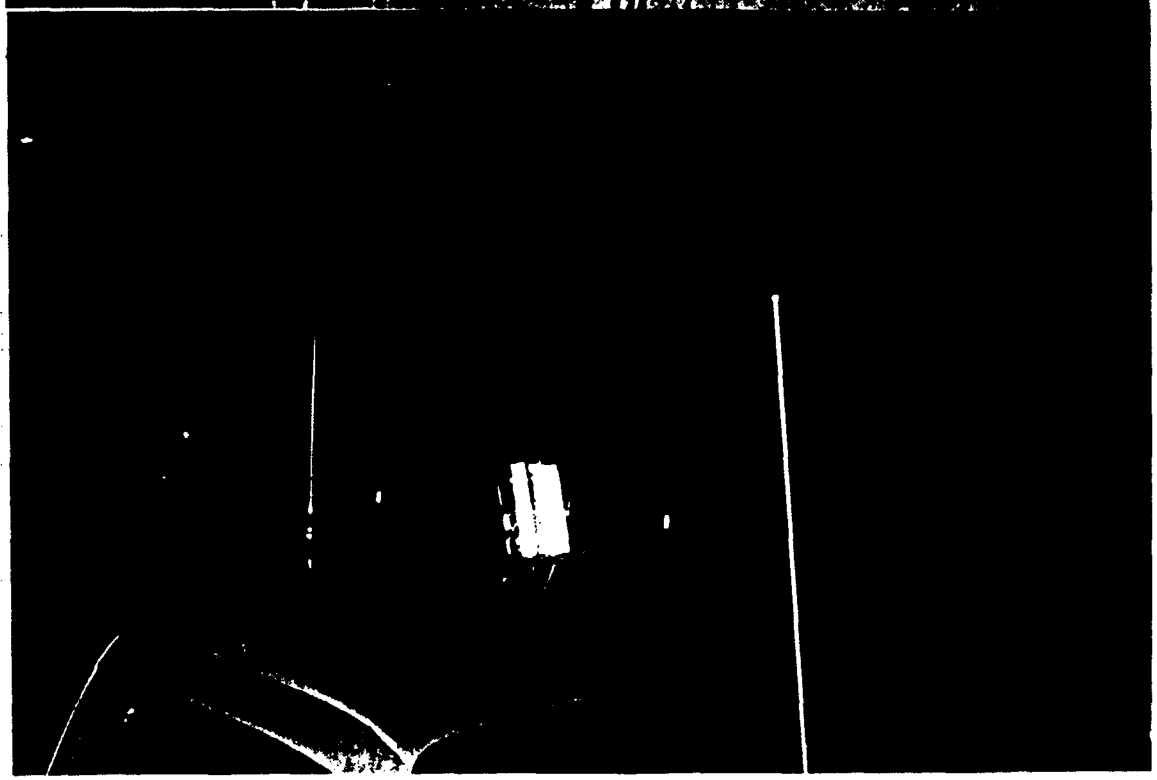


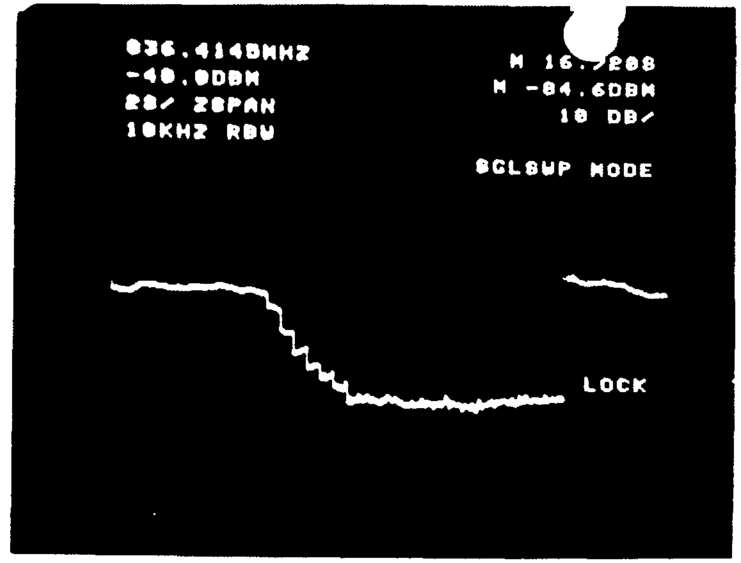
SITE 14: Garage Stall in Motel



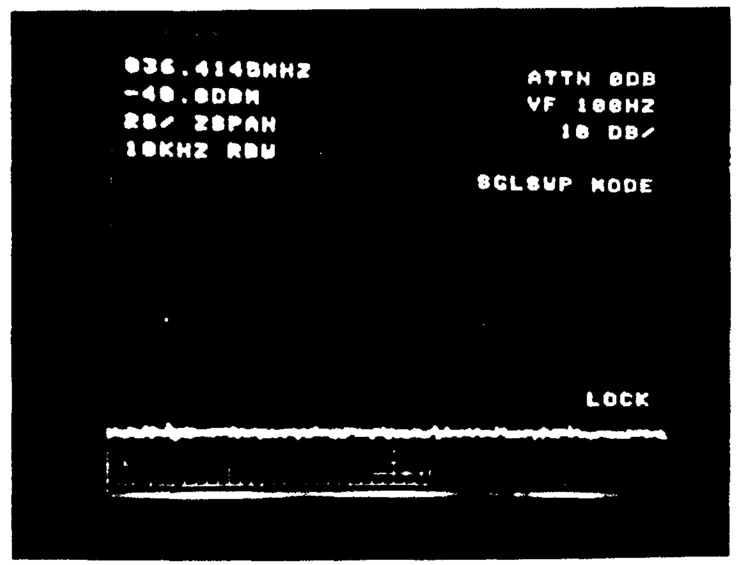
SITE 15: U-Haul Business
In Garage







SITE 15: Inside Metal Container
(Tire Changing Stand)



SITE 16: Adams & 30th (In Open)

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DAC

System Through Put Bit Error Rate Test

Date: July 26, 1990
Author: Bruce Lusignan
Report#: 900726-24

I. Test Programs:

Test programs for the DAC Base Station and User Unit have been written to test round-trip bit error rate. The test program in the Base Station, sends out a continuous stream of bits. Every scond, a two byte code word followed by 6 bytes of data are transmitted. The user program, locks to the bit stream and interprets the incoming data bit-by-bit. When the code word is received, the eight bytes of data are transmitted back from the User Unit exactly 10 bytes after reception. After this, another 2 bytes elapses and a single bit is transmitted to simulate the "status" function.

The program in the User Unit looks for the data only i the expected time slot and records the result. An analytical program compares round-trip received data with the transmitted data and records received bits and bit errors.

The overall Bit Error Rate (BER) can then be recorded by running the program for a number of transmissions and dividing errors by total bits received. Note that an error at the receiver unit will result in no transmission back to the base station. If this happens, the program detects the problem by comparing the code bytes and separates these events from the return bit error. Normally this does not effect the outcome of the test since the outgoing link has higher margin than the return link.

II. Equipment Setup:

The test setup of Figure 1 was used to test the system in the laboratory. The Base Station was used in its normal operational mode. In this mode it has 10 watts of transmit power. The antenna port from the duplexer is normally connected to low-loss coaxial cable going to a tower mounted high-gain antenna. For the test the antenna port is connected to a 10 dB, 30 watt attenuator to dissipate the transmit power. This is followed by a 50 dB attenuator. A long cable with 14 dB loss goes to the remote User Unit. Another two attenuators (labeled Attenuator A) further increase simulated path loss. One has 10 dB steps; the other 1 dB steps.

With Attenuator AV1 set to 50 dB, the overall attenuation from duplexer at the Base Station to Duplexer at the User Unit is 125 dB. This was confirmed by substituting the calibrated spectrum analyzer at point B, the E.F. Johnson receiver and measuring the signal received from the User transmitter. (Note that to measure lowest sensitivity, the two units must be physically separated by the cable and all cases tightly shut.)

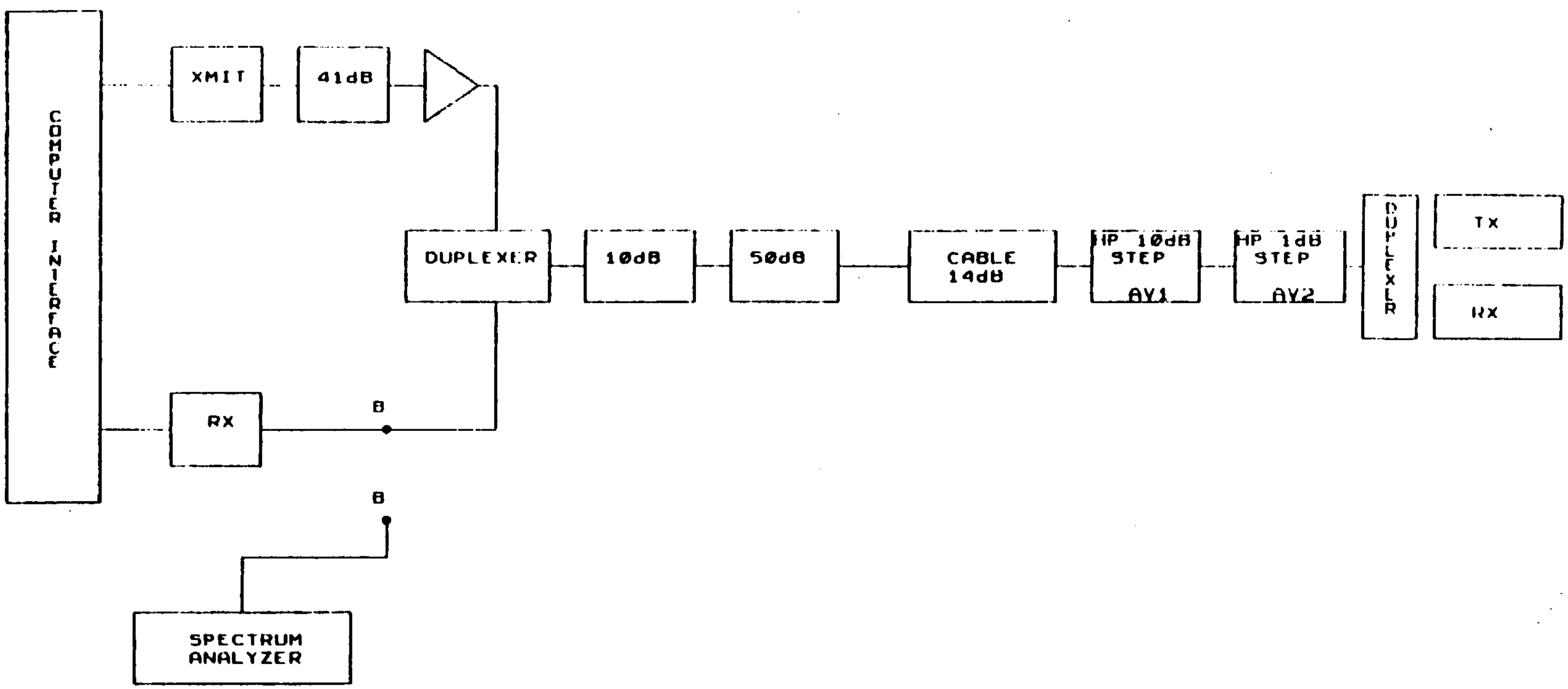
With the "path loss" between the Base Station and the User Unit as shown, the loss simulates three components: the gain of the Base Station antenna, the propagation loss between transmitter and receiver, and the gain of the User Unit antenna.

III. Test Results:

On July 23 and 24, 1990, the setup shown was used to measure the performance of Base Station A with User Unit 1. The results are shown in Table I. The data points are listed in order of weakening signal levels. Except for the data points with notes, all were acquired by running for about 20,000 data points. This resulted in no errors for signal strength greater than -104 dBm. to fill in data at greater power levels, long runs were made: 7, 10, and 13. Data points 20 and 21 resulted in error rates too great for the software to record correctly.

For data points 22 and 23 the signal strength was reduced so that errors finally began to appear at the User Unit. These rates of error were around 10^{-2} BER; they were characterized by failure of the User Unit to transmit about one time in four. Note that the User Unit must receive two bytes without error to be ale to transmit its response.

In these test both the User Unit and the E.F. Johnson radio began to pick up significant bit error rates at about -108 dBm. Independent measurement of the User Unit radio shows that the receiver noise power is about equal to the signal power when the signal level is -120 dBm. Thus, significant errors begin to appear at about 12 dB C/N; this is the expected value.



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Title		
BLOCK DIAGRAM		
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Date: September 12, 1990	Sheet 1 of 1	

FIGURE 1

July 23 1990

at a setting of 50dB at Attenuator B

~~at 50dB HP attenuator~~

Total Path loss = ~~124~~ 125 dB

Received power at Remote = ~~-83~~ -89 dBm

Received power at EF Johnson = ~~-101~~ -102 dBm

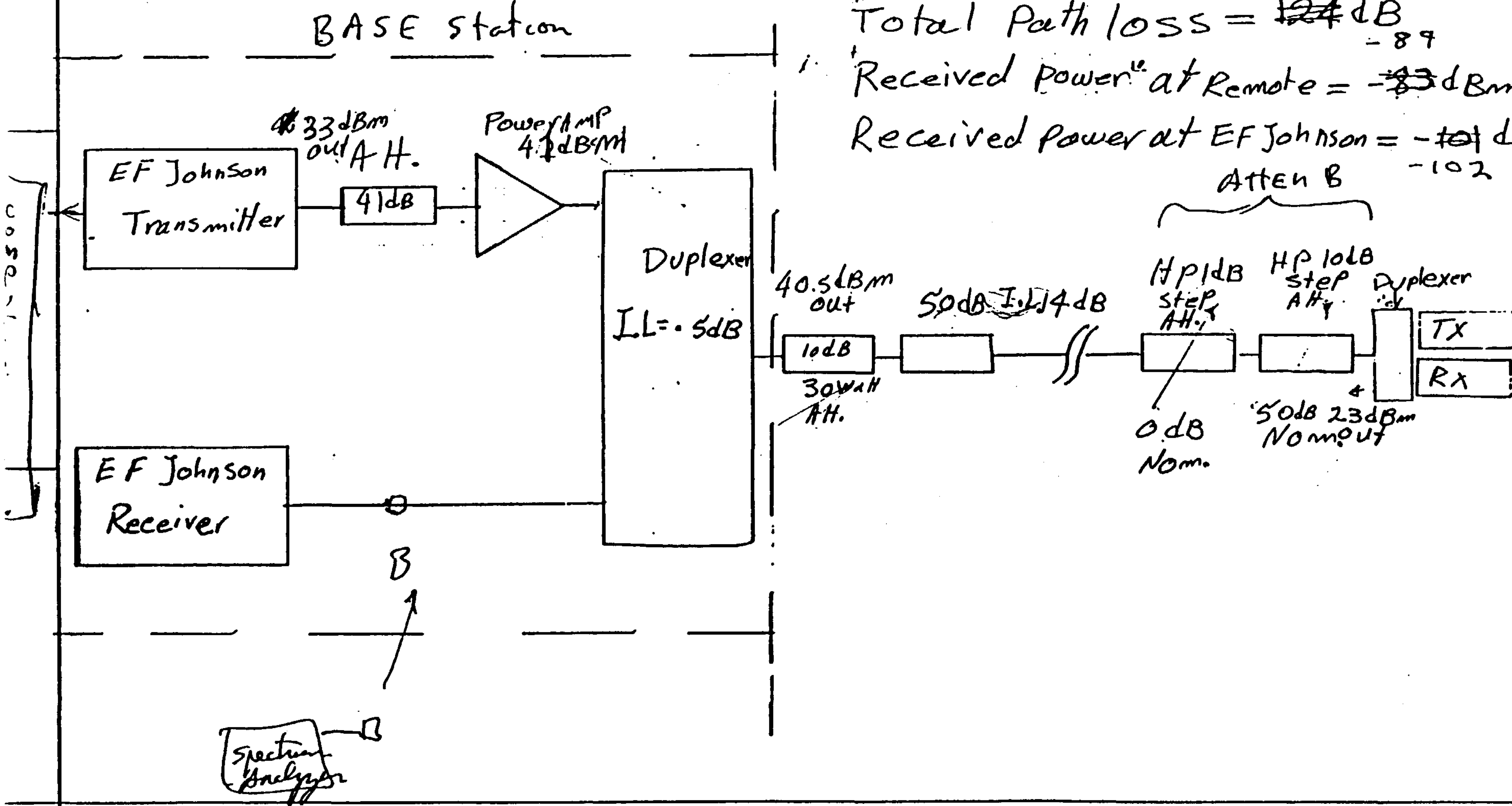


TABLE I

Performance of Base Station A with User Unit 1

Data Point	Atten dB	P_{USER} dBm	P_{BASE} dBm	Bits Rcvd	Errors bits	BER Fraction	Note
1	0	-34	-52	20,832	0	---	
2	10	-44	-62	21,504	0	---	
3	20	-54	-72	21,456	0	---	
4	30	-64	-82	21,504	0	---	
5	40	-74	-92	20,880	0	---	
6	45	-79	-97	21,744	0	---	
7	45	-79	-97	10,001,232	4	3.9×10^{-7}	long run
8	50	-84	-102	22,128	0	---	
9	52	-86	-104	22,992	0	---	
10	53	-87	-105	1,006,656	1	9.9×10^{-7}	long run
11	54	-88	-106	20,448	2	9.7×10^{-5}	
12	55	-89	-107	21,456	1	4.7×10^{-5}	
13	55	-89	-107	101,472	1	9.85×10^{-6}	long run
14	56	-90	-108	21,120	18	8.5×10^{-4}	
15	58	-92	-110	20,496	198	9.7×10^{-3}	
16	58	-92	-110	21,552	273	1.26×10^{-2}	
17	60	-94	-112	22,176	507	2.2×10^{-2}	
18	60	-94	-112	21,120	394	1.8×10^{-2}	
19	62	-96	-114	20,352	635	3.12×10^{-2}	
20	64	-98	-116	---	---	Too great to measure	
21	66	-100	-118	---	---	Too great to measure	
22	72	-106				Lose response user	
23	74	-108				Lose response user	

IV. Implication on Link Design:

The data system is designed with a link Base-to-User that has 18 dB more margin than the return link. The imbalance serves several purposes. First, it compensates for more local noise that may occur at user sites. User Units must be placed at all locations, even those with heavy local interference such as high power switches, while the Base Station can be located away from severe interference. Second, the User Unit cost is kept low by reducing its transmit power. Third and finally, the data handling system presumes an imbalanced link. A lack of correct response at the Base immediately results in a repeat request. In a later stage of software refinement, repeated transmissions from a weak station can be averaged to correct errors, further enhancing the return link.

V. Coverage Expectations:

The level at which the User transponders can be expected to begin to lose significant data is 131 dB equivalent "path loss." The "path loss" of the test assumes 0dB antenna gains, in the actual cell coverage, an antenna with 8 dB gain is always used at the Base Station. The User Unit uses an omnidirectional antenna with about 1.5 dB gain or, if necessary, it can use a directional antenna with 8 dB gain. The free space loss limit is thus:

$$-L_{fs}max = 131 + 8 + 1.5 = 140.5 \text{ dB} \ . \ . \ . \text{ Omni User}$$

$$-L_{fs}max = 131 + 8 + 8 = 147 \text{ dB} \ . \ . \ . \ . \ . \text{ Direct. User}$$

Two applications are of interest. One is a line-of-sight monitoring at a distance. For this application, a free space loss plus a fading margin provide the appropriate range estimate.

The equation for the free space loss, L_{fs}, is:

$$L_{fs} = 20 \log (\ /2nD)$$

where is the wavelength of the radio waves:

in = 0.323 M

out = 0.315 M

The inbound link is the limiting one.

For 99.9% reliability in a line-of-sight relay, the fade margin required is 27 dB. Thus the allowed L_{fs} with margin is:

$$-L_{fs} \text{ margin} = 113.5 \text{ dB, with Omni User Antenna}$$

$$-L_{fs} \text{ margin} = 120.0 \text{ dB, with high gain User Antenna}$$

The range, D, is given by:

$$D = \frac{}{} 10^{-L_{fs}/20}$$

D with omni = 24.32 km = 15.1 miles

D with high gain = 51.41 km = 31.9 miles

When there is a clear line-of-sight between Base Station and User Unit, the User Unit can be up to 15 miles away and still operate 99.9% of the time. If an antenna with 8 dB gain is used to point back to the Base Station, then up to 31.9 miles can be achieved with 99.9% reliability.

These limits assume that the Base Station is located in a relatively low-noise environment. Since the path Base-to-User Unit has about 18 dB extra path margin, the User Unit could be located in a noisier environment.

VI. Area Coverage:

The second application is area coverage of a cell. The PG&E tests are being run at a fairly low tower in the San Rafael area. Because of the mountainous area, there is a blockage by nearby terrain. Detailed elevation data and the propagation models developed by the U.S. Bureau of Standards have been used to plot contours of equivalent free space loss. This accounts for statistical variations and normally has a 20 dB margin to account for a local building, multipath, etc. It is based on a receiver located 2 meters above ground, i.e., a car-top antenna.

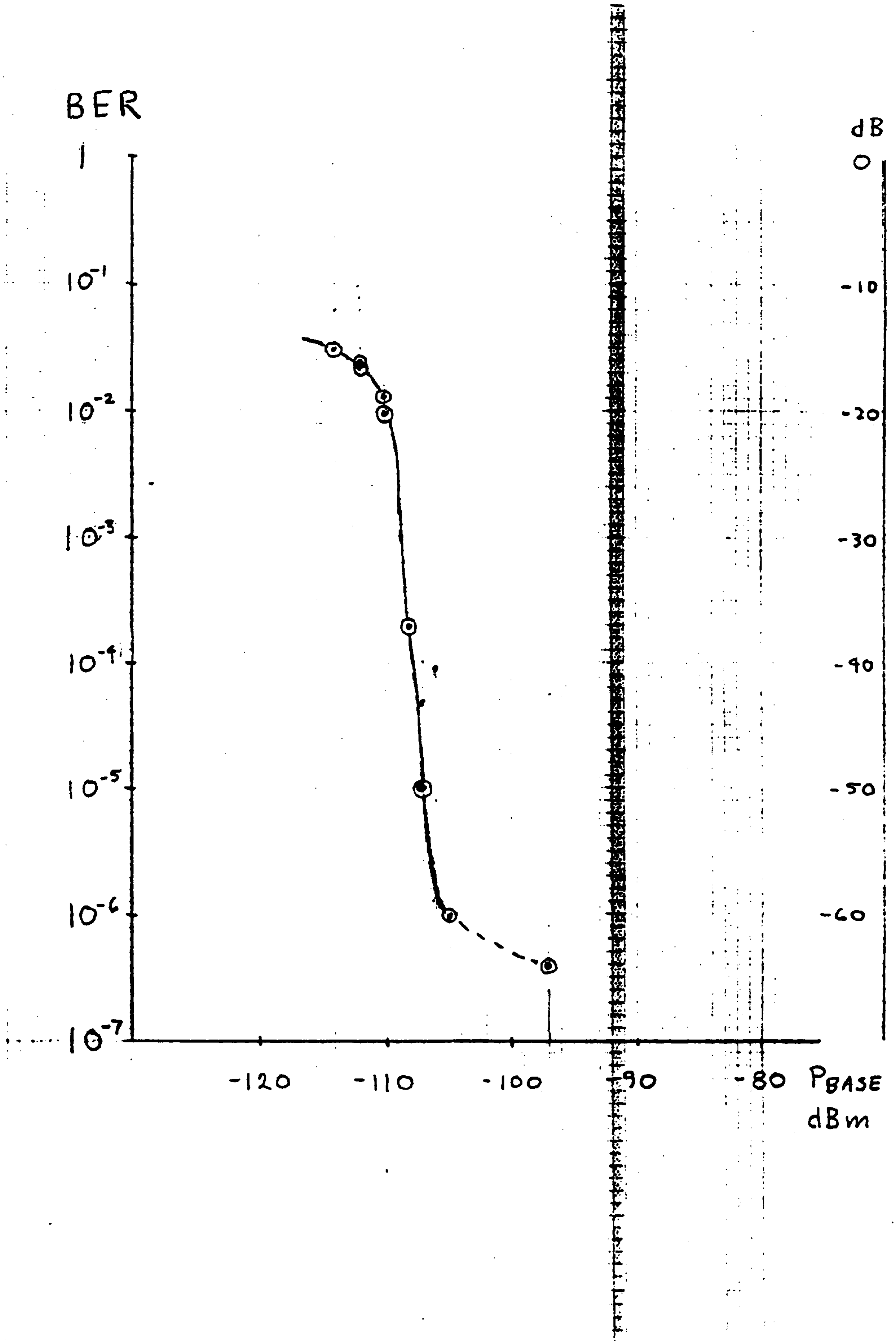
Figure 2 shows the coverage contour for -149.5 dB equivalent path loss. At the edge of this contour, a directional antenna may or may not be required depending on the local installation. The shortest distance in this contour is one mile, corresponding to sites on the other side of an intervening mountain ridge. The longest distance is 18 miles. Corresponding to a relatively clear line-of-sight out to San Francisco Bay. Except for the direct blockage by hills, the coverage contour is typically 3 miles. Note: In the program for Figure 2, the computer program was used to calculate a 37 dBu contour with an effective radiated power of 20 dBW from the PG&E test tower (10 dBW into a 10 dB gain antenna). This is converted to "equivalent path loss" using the conversion factor from dBu to Watts/M^2 (0 dBu = -145.7 dBW/M^2) and the effective area of a 0 dB gain antenna:

$$Aeff = {}^2/4n = .0083\ M^2 = -20.8\ dBM^2$$

The conversion is:

$$\text{Effective path loss} = 37\ \text{dBu} - 20\ \text{dBE}_{irp} - 145.7 - 20.8$$

$$\text{Effective path loss} = -149.5\ \text{dB path loss.}$$


BER
1
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
-120
-110
-100
-90
-80
P BASE dBm
dB
0
-10
-20
-30
-40
-50
-60

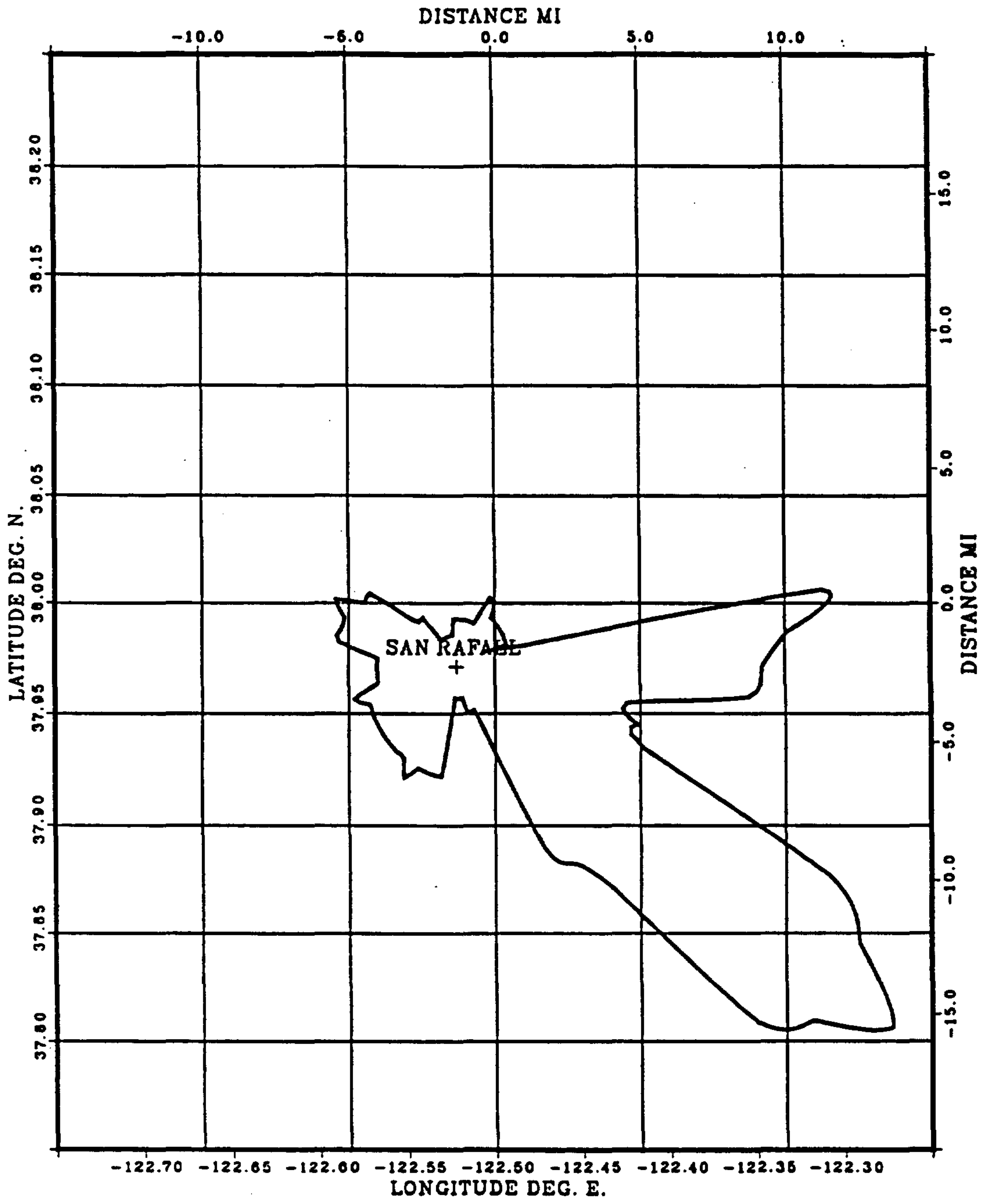
Similarly, the 17 dB contour gives -169.5 dB path loss and a 57 dB contour gives -129.9 dB path loss.

Figure 3 shows the contour for -129.5 dB equivalent path loss. No directional antenna would be needed under normal circumstances within this area. There is enough margin to overcome attenuation indoors or behind buildings. Only very special circumstances (i.e. a radio in a sealed metal enclosure) would require some supplement. This area covers 2 miles typically.

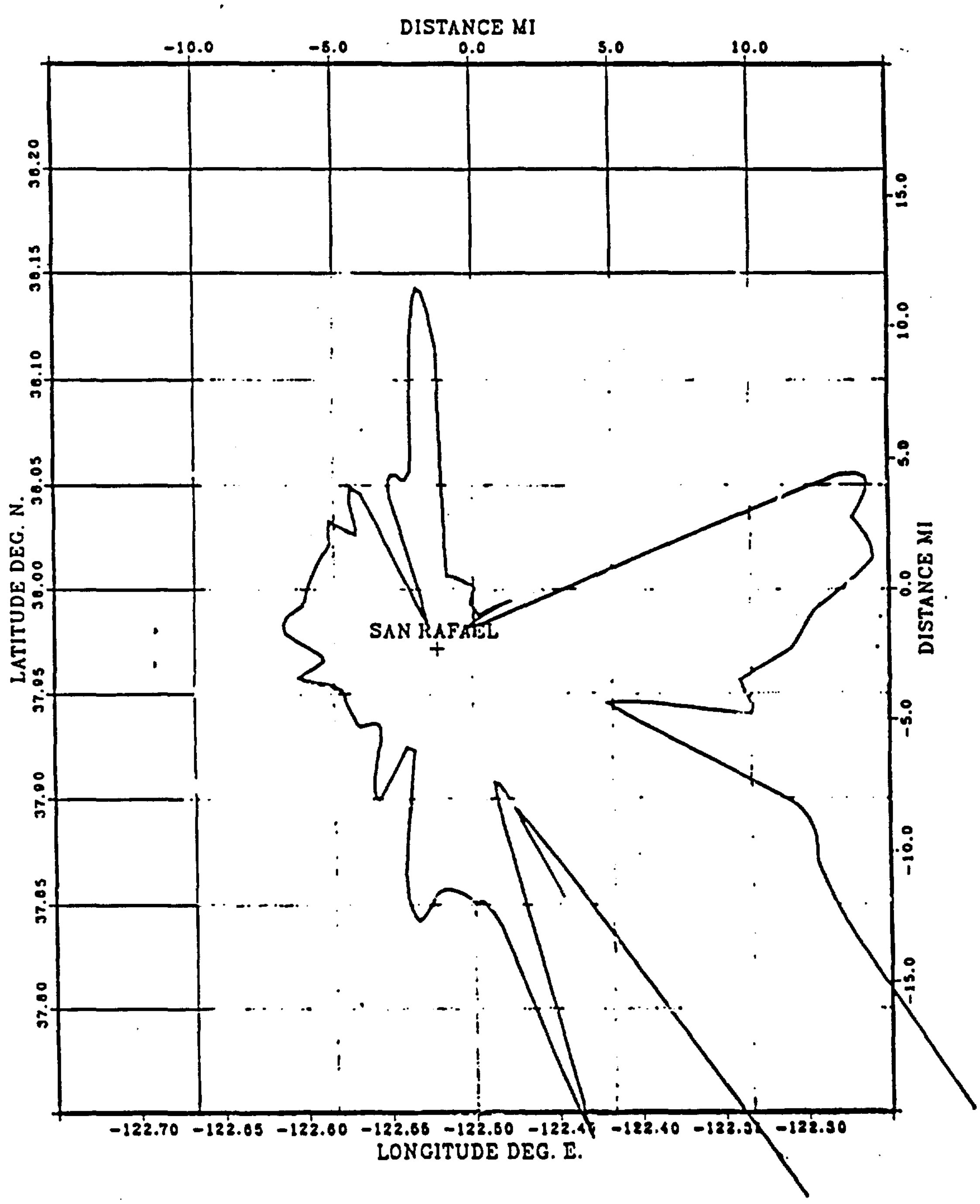
Figure 4 shows the coverage with -169.5 dB path loss, about 20 dB over the measured limit. With this margin, diffraction over the computer mountain ridges helps fill in the shadow areas behind. Since the model normally allows about 20 dB of building shielding, sites out to this contour could normally receive coverage by combining a directional antenna, installation at some height on a building and location on the building side facing the Base Station.

Figure 5 shows the nominal coverage contour (Figure 2) superimposed on a contour map of the test site. The 22 sites tested are also shown.

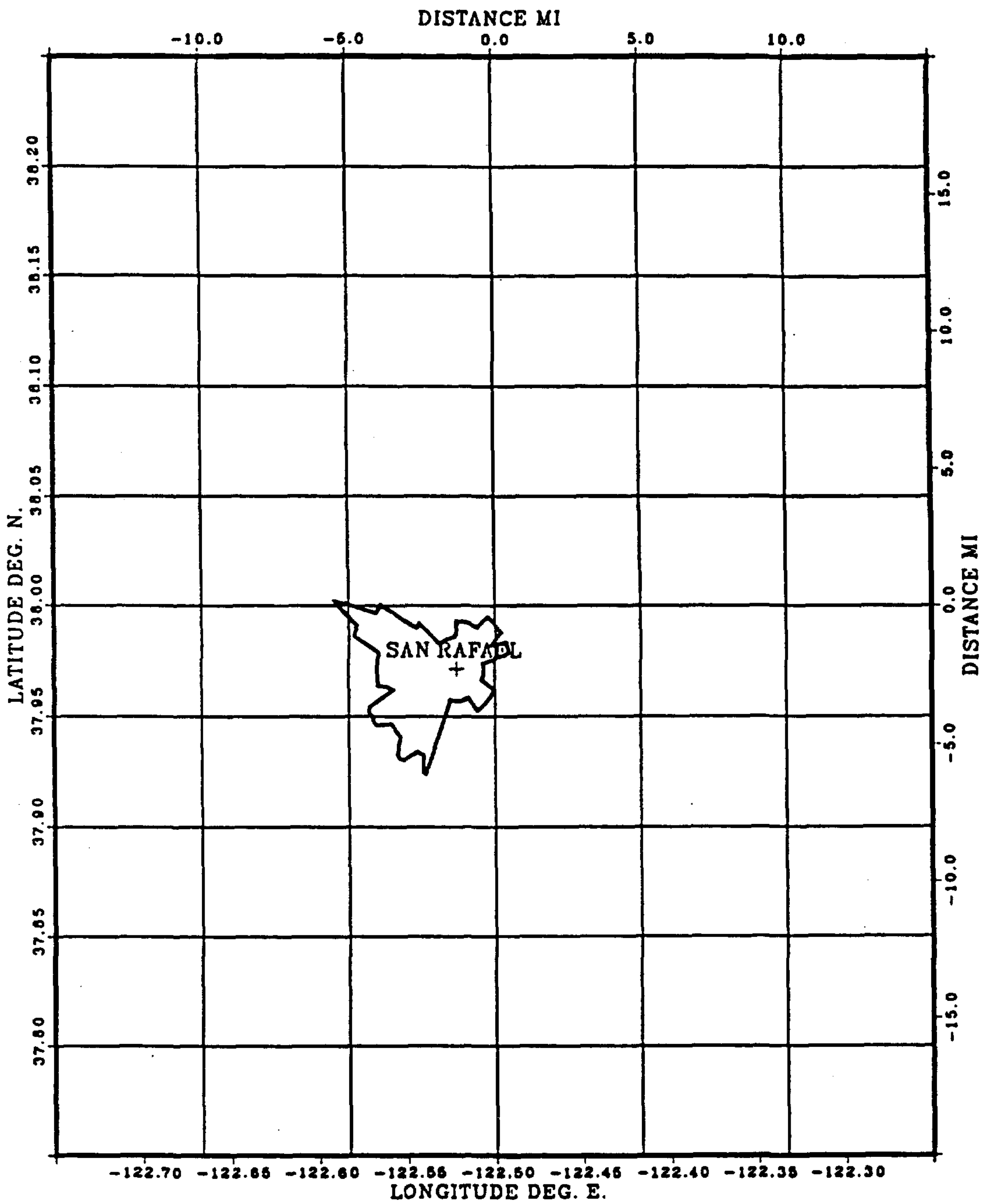
57 dBU Coverage Contour at San Rafael Site



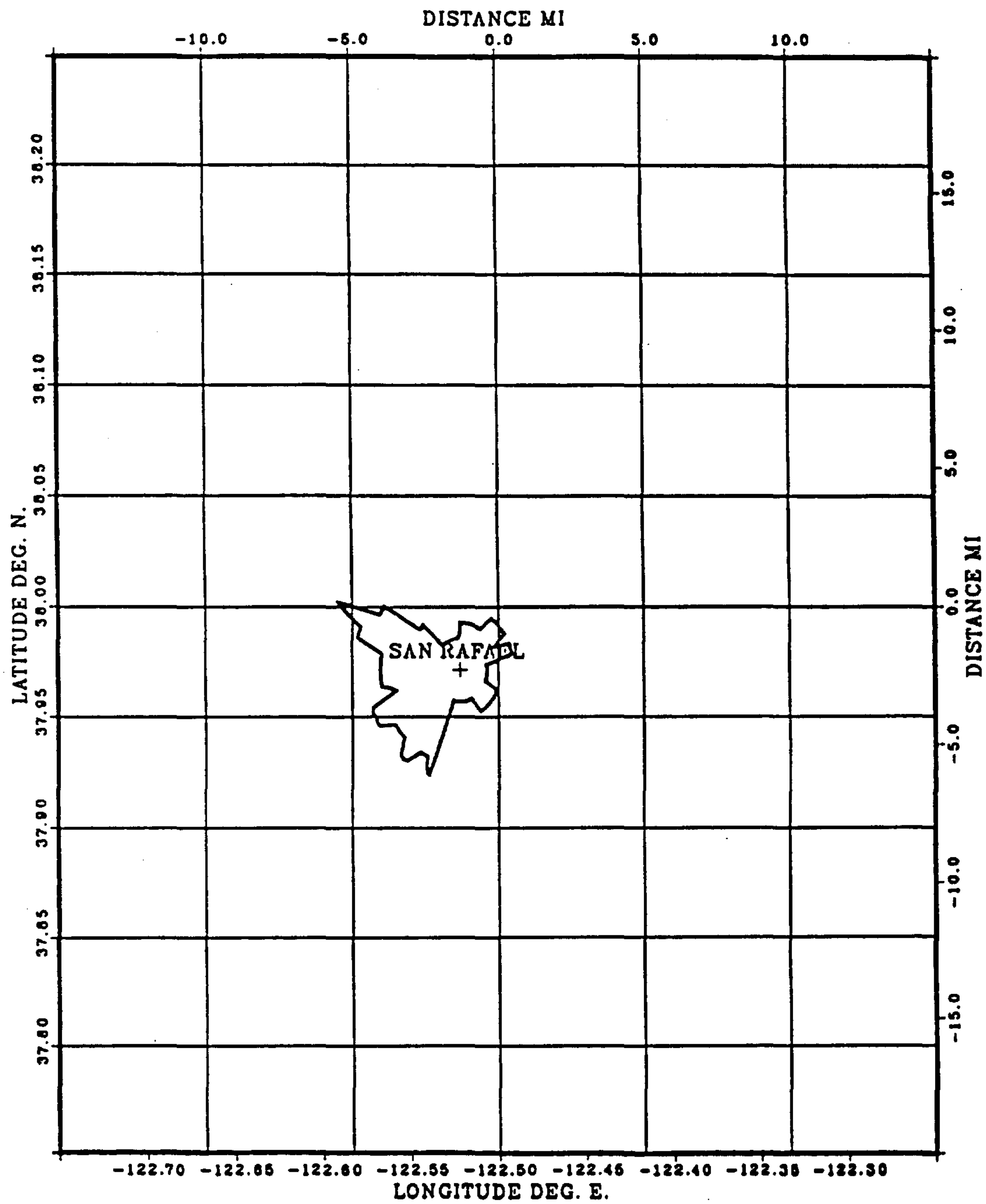
17 dBU Coverage Contour at San Rafael Site



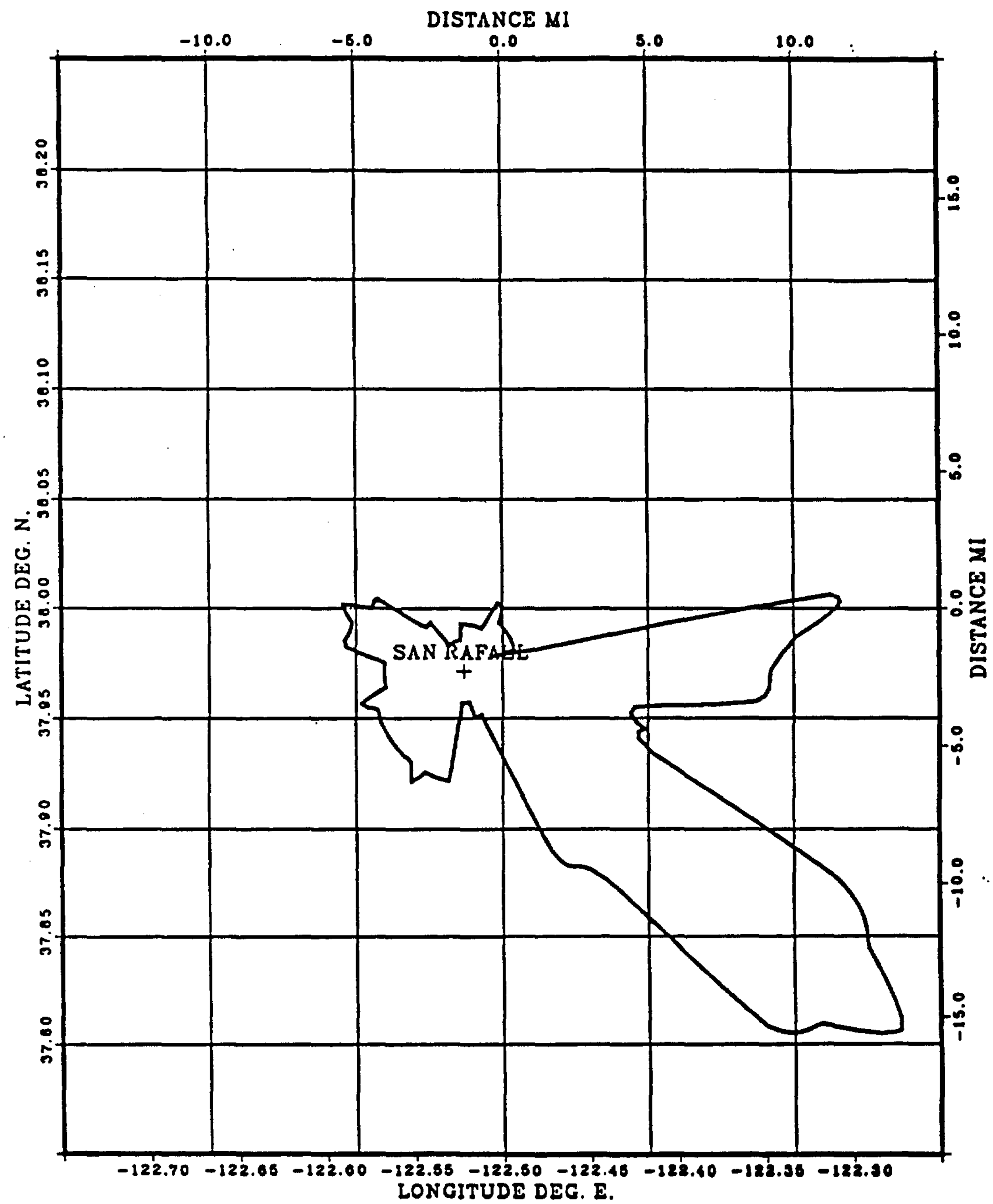
57 dBU Coverage Contour at San Rafael Site



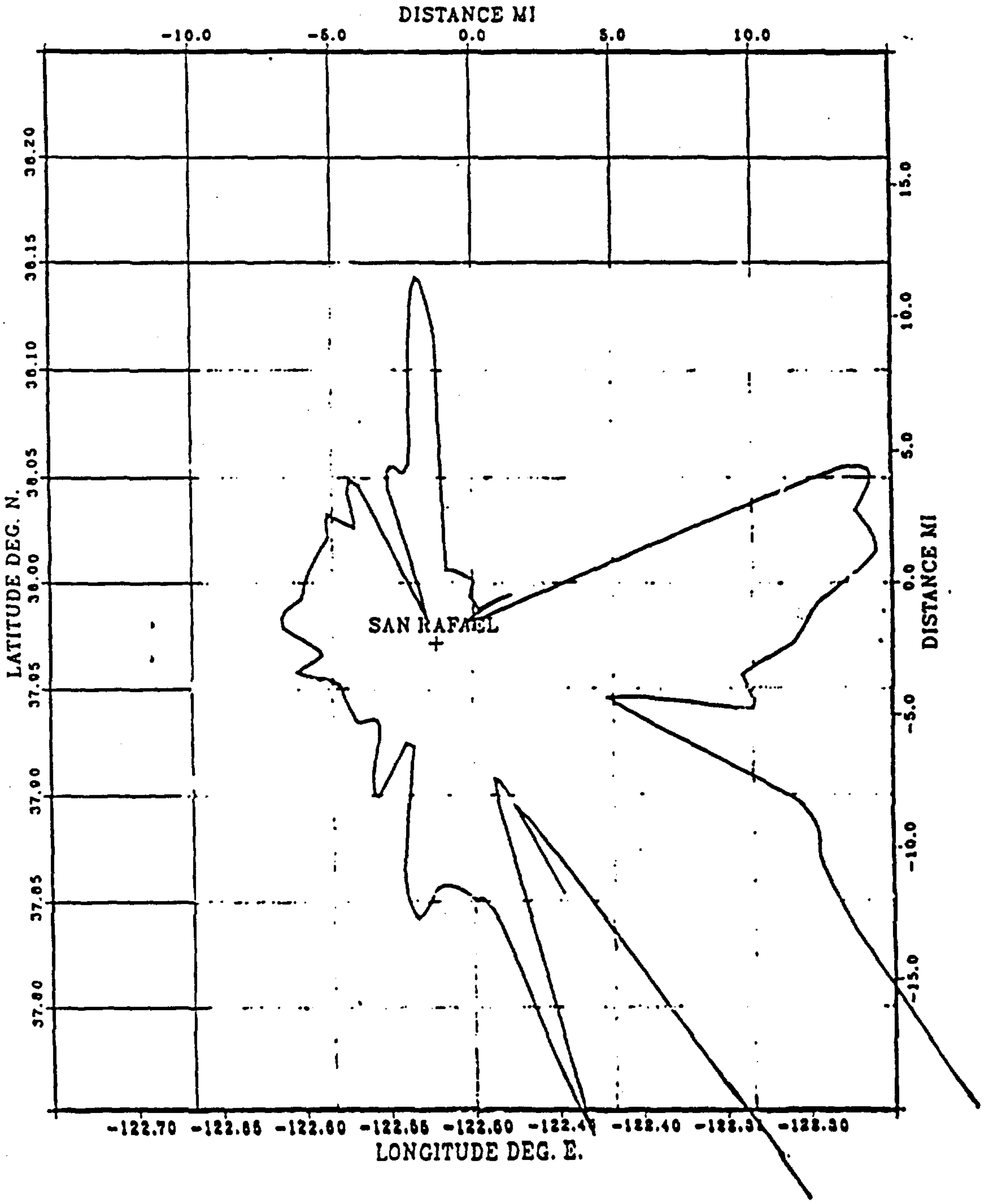
57 dBU Coverage Contour at San Rafael Site



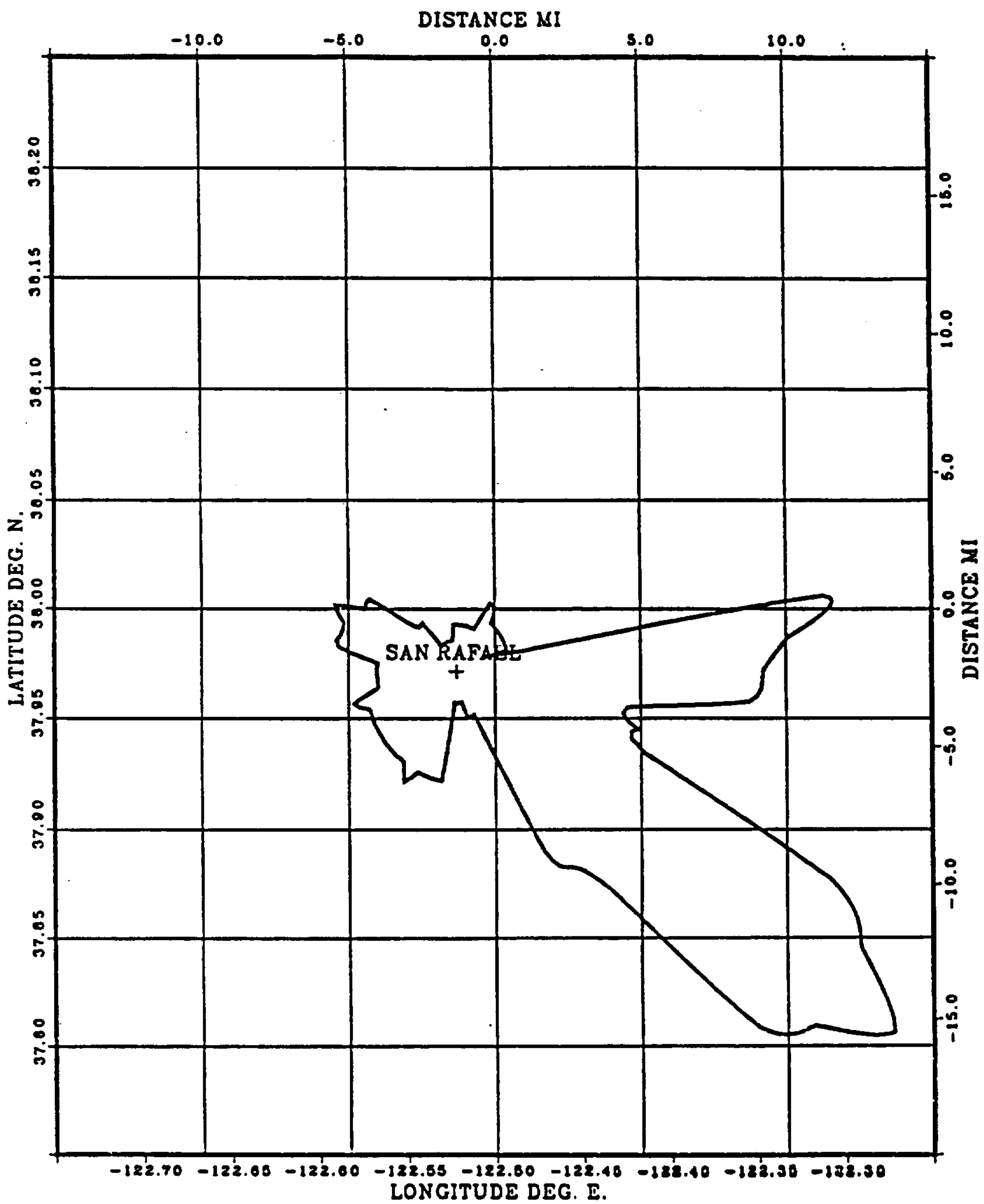
$7 dBU Coverage Contour at San Rafael Site



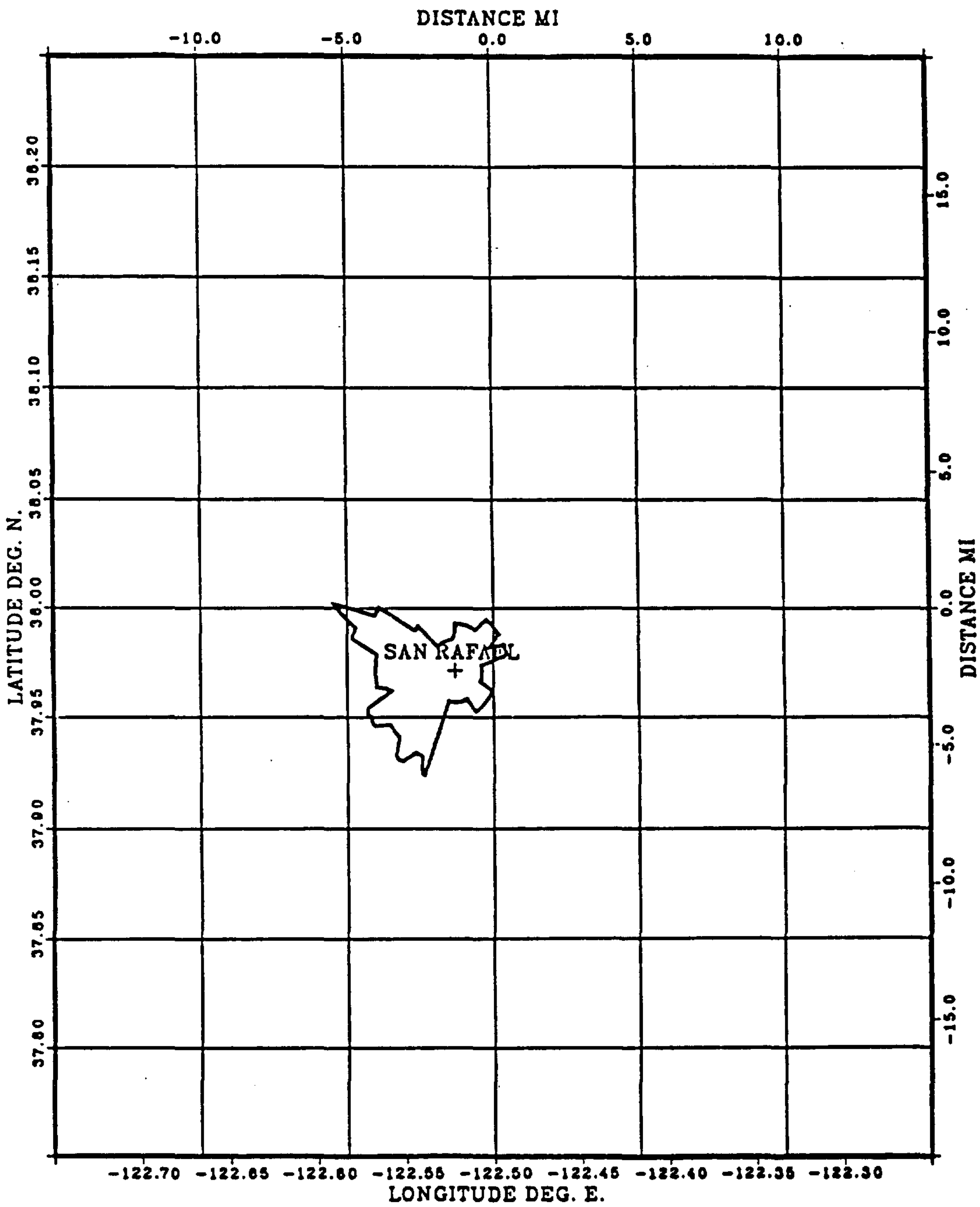
17 dBU Coverage Contour at San Rafael Site



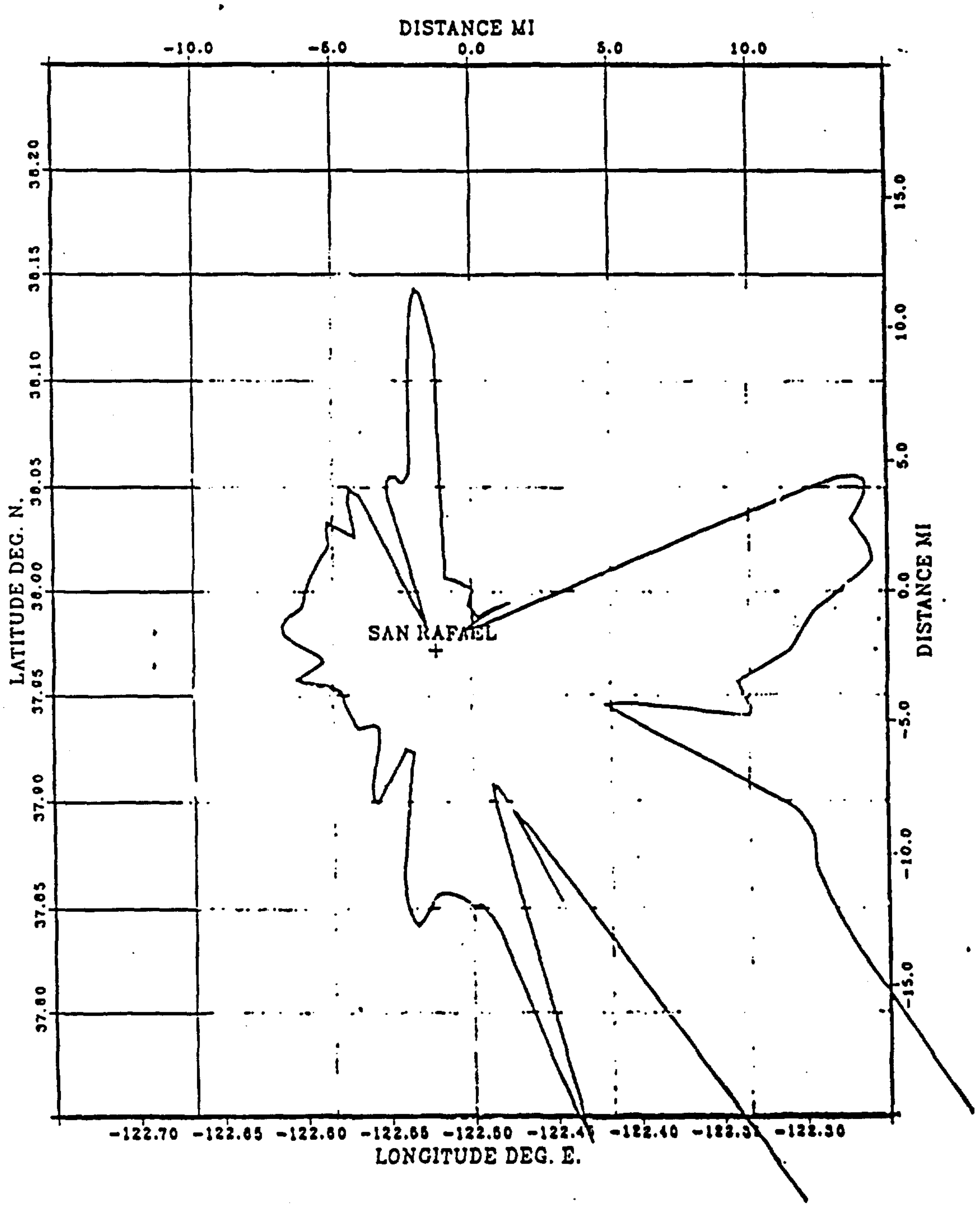
57 dBU Coverage Contour at San Rafael Site



57 dBU Coverage Contour at San Rafael Site



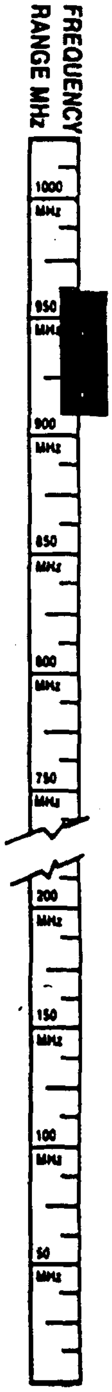
17 dBU Coverage Contour at San Rafael Site



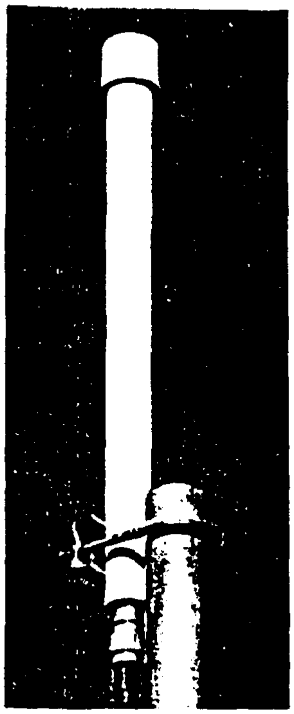
920 - 960 MHz

Data Stick
ANT960F0

The Telewave ANT960F0 "DATA STICK" was designed as an economical antenna for use with data systems. Its rugged all brass construction is housed in a durable PVC radome. It is designed to withstand ice, snow, high winds and the most severe weather conditions. Its PVC radome will not corrode, even in the presence of saltwater, oil and most common chemical fumes.



BANDWIDTH The ANT960F0 "DATA STICK" offers a full 40 MHz of bandwidth.

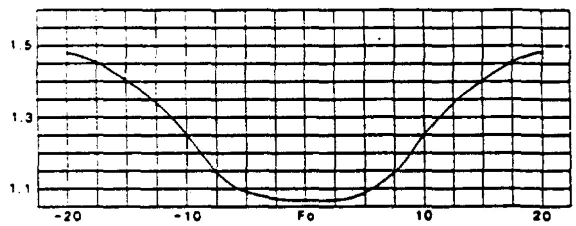


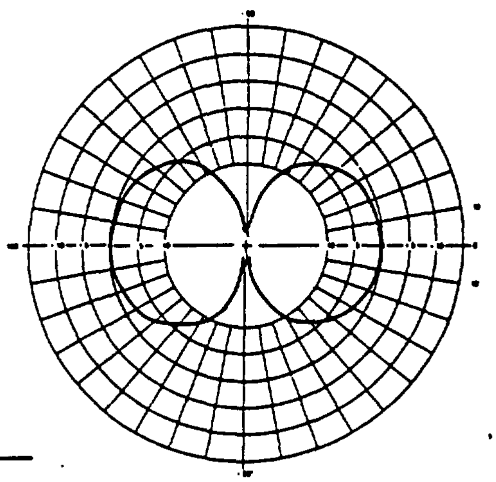
ELECTRICAL SPECIFICATIONS

Power Rating	125 Watts
Gain	Unity
Frequency Range	920-960 MHz
Bandwidth	40 MHz
VSWR	1.5:1 or less
Impedance	50 Ohms
Vertical Beamwidth	42 Deg.
Pattern	Omni
Polarization	Vertical
Termination	Recessed N-Type Male

MECHANICAL SPECIFICATIONS

Dimensions (inches)	14.5
Weight (lbs.)	.75
Max Rated Wind Velocity (mph)	90
Max Rated Wind Velocity 0.5 in radial ice (mph)	90
Mounting Information	Clamp for mounting to a 1¼" to 1½" mast optional
Shipping Information	UPS Shippable





VSWR vs. FREQUENCY

TYPICAL RADIATION PATTERN

Vertical radiation pattern for vertical polarization

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806 - 960 MHz

Telewave

10 dB

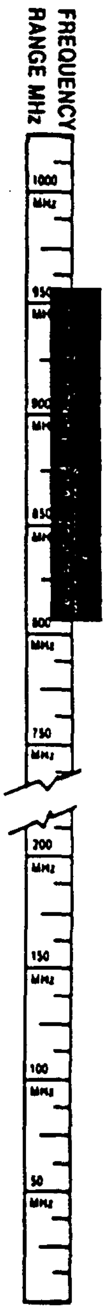
Yagi Antenna

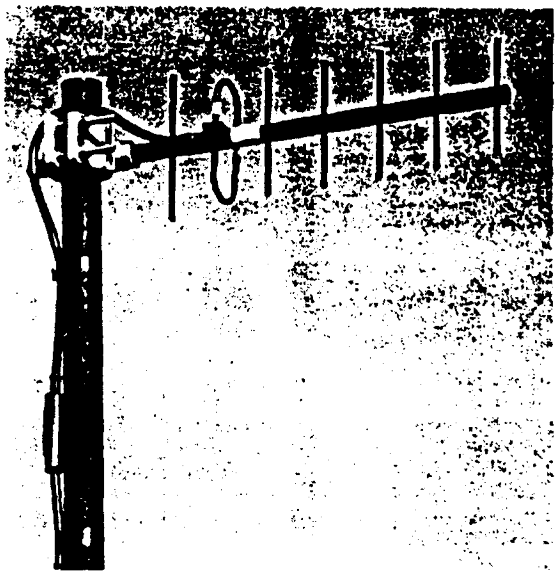
ANT860Y10

The Telewave ANT860Y10 is a rugged, high quality directional antenna, designed for control or point to point applications. This seven-element, 10 dB gain antenna was designed to provide high directivity and high front-to-back ratio under the most adverse conditions. All elements are at DC Ground potential for lightning protection. The antenna is all brass construction which is welded at the base connection to prevent intermodulation. It is then painted with a high-tech, special blend, protective coating designed to withstand hostile environments and aid in de-icing.

BANDWIDTH The ANT860Y10 offers a full 60 MHz bandwidth. Specify frequency when ordering.

MOUNTING The ANT860Y10 ships standard with a clamp set for easy orientation for either vertical or horizontal polarization.



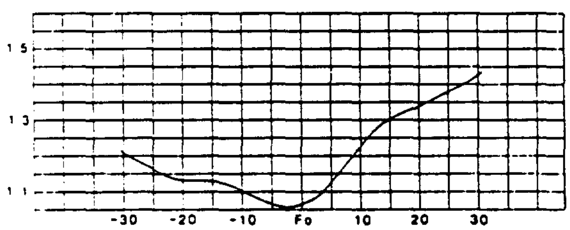


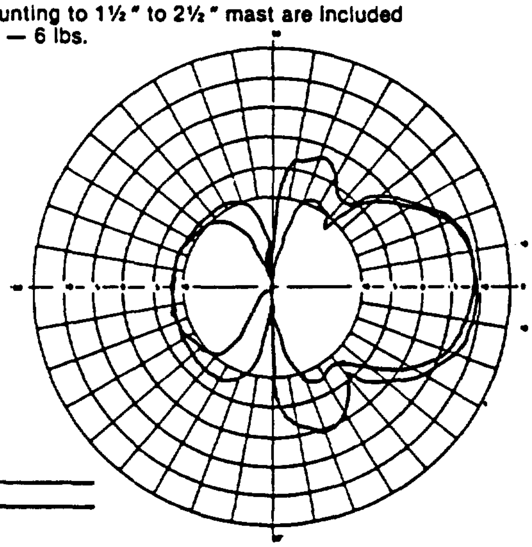
ELECTRICAL SPECIFICATIONS

Power Rating	150 Watts
Gain	10 dB
Front-To-Back Ratio	15 dB min.
Frequency Range	806-960 MHz
Bandwidth	60 MHz
VSWR	1.5:1 or less
Impedance	50 Ohms nominal
Vertical Beamwidth	49 Deg.
Horizontal Beamwidth	47 Deg.
Pattern	Directional
Polarization	Vertical or Horizontal
Lightning Protection	DC Ground
Termination	N-Type Male

MECHANICAL SPECIFICATIONS

Dimensions (inches)	27"L × 7"W
Weight (lbs.)	4
Max Rated Wind Velocity (mph)	150
Max Rated Wind Velocity with 0.5" Radial Ice (mph)	125
Max Exposed Area Flat Plate Equivalent	.23 sq. ft.
Lateral Thrust at 100 MPH (40 PSF flat equivalent)	6.04 lbs.
Bending Moment At Top Clamp At 100 MPH (40 PSF flat equivalent)	20.8 ft. lbs.
Mounting Information	Clamps for mounting to 1½" to 2½" mast are included
Shipping Information	UPS Shippable — 6 lbs.





VSWR vs. FREQUENCY

TYPICAL RADIATION PATTERN

Horizontal radiation pattern for horizontal polarization

Horizontal radiation pattern for vertical polarization

Specifications are subject to change without notice.

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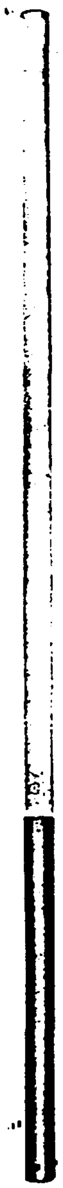
806/941 MHz

Model
ASP-973
SERIES
ASPD974
(inverted mounting only)



10 dB Gain, -2 Degree Beamtilt Omnidirectional Fiber Glass Antenna.

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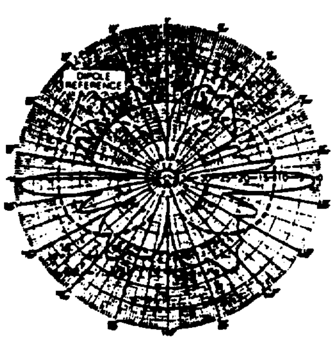
- **High Gain** — 10 dB major lobe gain assures maximum omnidirecitonal signal saturation
- **Broadband** — entire frequency range coverage with 500 watt power rating for maximum combining usage
- **Extremely Rugged** — 165 mi/h (265 km/h) wind rating includes 1.65 survival safety factor to guarantee minimum beam bending in high or gusty winds
- **Lightweight** — only 27 lb (12.3 kg) means no special erection cranes or fixtures are necessary

SPECIFICATIONS

Electrical	
Power	500 watts maximum
Gain	10 dB [illegible]
Frequency Range	806-869 MHz (ASP-973) Trunking/conventional
	824-880 MHz (ASPE973) non-wire line cellular
	824-896 MHz (ASPD974) cellular, inverted mounting ONLY
	835-894 MHz (ASPF973) wire line cellular
	890-941 MHz (ASPG973) Trunking/conventional
Impedance	50 ohms nominal
VSWR	1.5:1 (maximum over frequency range)
Vertical Beamwidth	6°
Beam Downtilt	2°
Lightning Protection	Direct ground
Termination	N female (no "pig-tail" supplied)
Mechanical	
Rated Wind Velocity (RS-329)	165 mi/h (265 km/h)
Equivalent Flat Plate Area	1.6 ft² (0.14 m²)
Lateral Thrust	65.1 lb (29.5 kg)
Bending Moment	372 ft-lb (51 kg-m)
Length	14 ft (4.3 m)
Weight	27 lb (12.3 kg)
Support	2⅞ inch (7,3 cm) dia. aluminum pipe
Mounting	Two (2) heavy duty mast clamps recommended (furnished)*
Shipping Information	
Weight	56 lb (25.4 kg)
Dimensions	4½ inches (11.4 cm) O.D. x 171 inches (435 cm)

Vertical Radiation Pattern



*See catalog sections for mounting hardware, cables, connectors and other materials required for complete installation.